PPPL
Collaboration Opportunities

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ARPA-E ALPHA Annual Review

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U.S. DEPARTMENT OF ENERGY

PRINCETON UNIVERSITY

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Princeton Plasma Physics Laboratory

US Dept. of Energy
Office of Science
National Laboratory

- ~500 FTE employees
  incl. 20 postdocs
- 38 graduate students

~ 350 visiting scientists
(40 resident)

Founded 1951

Managed & operated
by Princeton University

www.pppl.gov

U.S. DEPARTMENT OF ENERGY | Office of Science

PPPL PRINCETON PLASMA PHYSICS LABORATORY

PRINCETON UNIVERSITY

PPPL Focus is on Fusion and Plasma Physics

- Magnetic fusion (primarily)
  - How to improve plasma confinement efficiency?
  - Compact configurations; simpler systems
  - Predictive understanding, scientific foundations for fusion
  - Integrated physics & engineering reactor studies
- Plasma astrophysics, extreme states of matter
  - HEDP
- Novel plasma applications
  - Diagnostic techniques
  - Accelerators
  - Materials processing, nano-material production

PPPL Strengths & Collaboration Opportunities

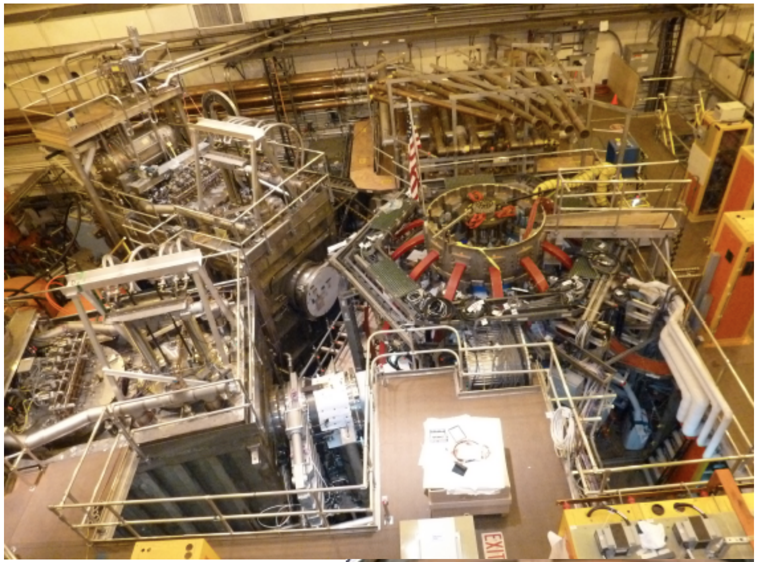
- Theory & modeling
  For a wide range of configurations

- Advanced diagnostic approaches

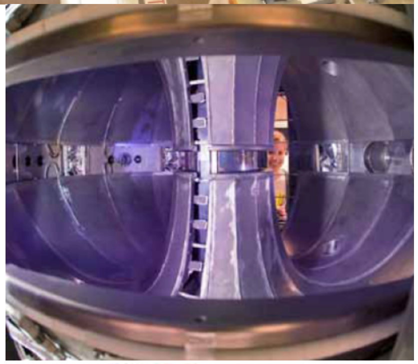
- Engineering design and modeling
  - System design: mechanical, electrical, vacuum, cryogenic, rad. safety
  - Heating systems: neutral beams, RF, high power accelerators
  - Pulsed power (on site: 2GJ stored, ~1GW pulsed)

- Construction, operation of large & small collaborative facilities
  - NSTX-U
  - LTX, MRX, FLARE
  - PFRC-2, Paul-trap simulator, Plasma-nano lab., proto-Ptolemy

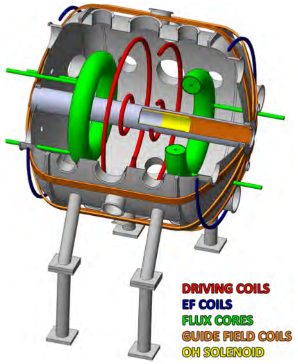
NSTX-U



LTX

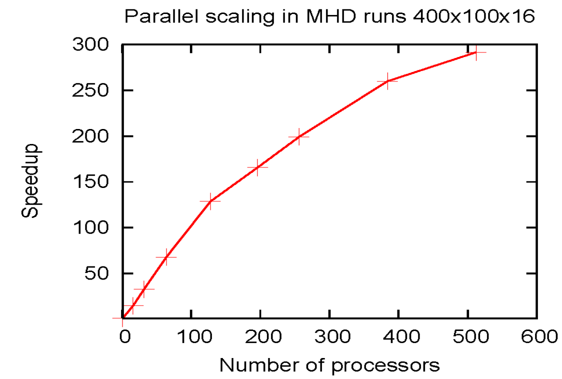


FLARE

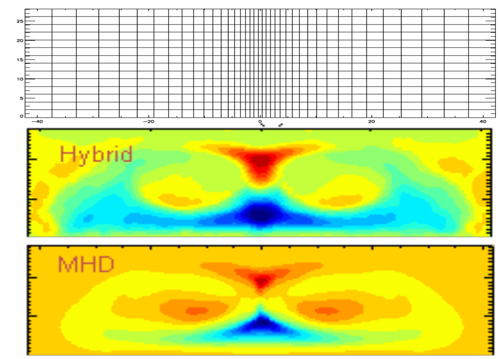


HYbrid and MHD simulation code (HYM): Models

- 3-D nonlinear MHD
- Physical models:
  - Resistive MHD & Hall-MHD.
  - Hybrid (fluid electrons, particle ions).
  - MHD/particle (one-fluid thermal plasma + energetic particle ions).
- Full-orbit kinetic ions.
- Delta-f or full-f numerical scheme.
- Self-consistent equilibria, including beam ion effects [Belova et al, Phys. Plasmas 2003].
- Flexible geometry/ adaptive grid.
- Flexible boundary conditions:
  - Periodic, perfectly conducting, end-shorting, applied value of E at the ends, and etc.
- Parallel (3D domain decomposition, MPI).
- IDL and VisIt visualization.



HYM shows good parallel scaling up to 500 processors for production-size jobs, and allows 3D MHD simulations of spheromak merging to be performed in < 2 wall-clock hours.



(a) Example of an adaptive grid. (b-c) Toroidal velocity from 2D hybrid simulations and MHD simulations of counter-helicity spheromak merging.

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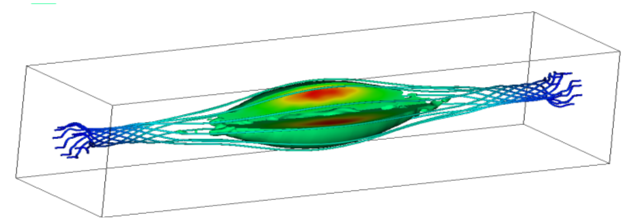
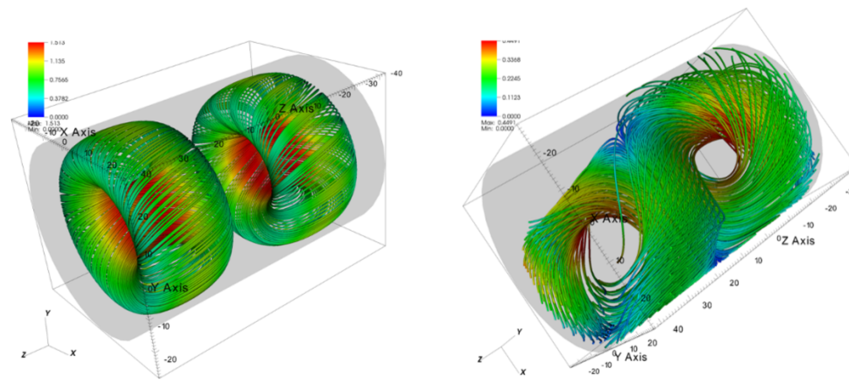
HYbrid and MHD simulation code (HYM): Applications

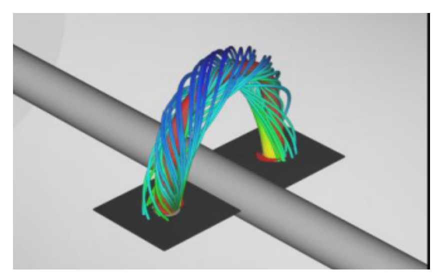
- ICC Theory and Modeling
  - Thermal ions kinetic effects on FRC stability.
  - Effects of beam ions on FRC stability.
  - FRC spin-up mechanisms.
  - 3D MHD, Hall-MHD, and Hybrid simulations of spheromak merging (co- and counter-helicity).
  - 3D simulations of the MRX-magnetic arc experiments.
- FRC – Tri-Alpha collaboration
  - Rotation control
  - n=2 rotational and n=1 wobble modes.
  - Beam ions effects.
- NSTX
  - Sub-cyclotron frequency Alfven eigenmodes (GAE and CAE).



3D hybrid simulation of FRC with end-shorting boundaries.



3D field-line plots of initial and relaxed states from co-helicity merging simulations. The final magnetic structure is a minimum-energy Taylor-eigenstate.



3D MHD simulation of magnetic flux-rope evolution.

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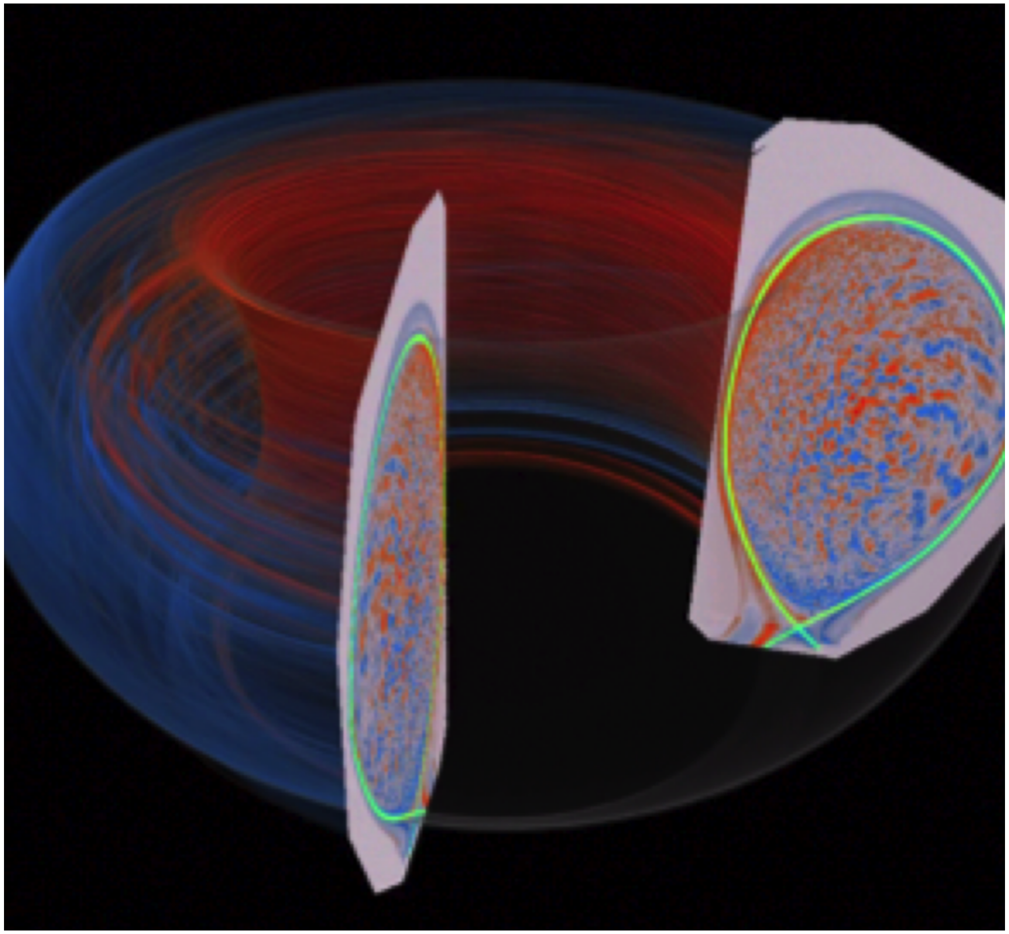
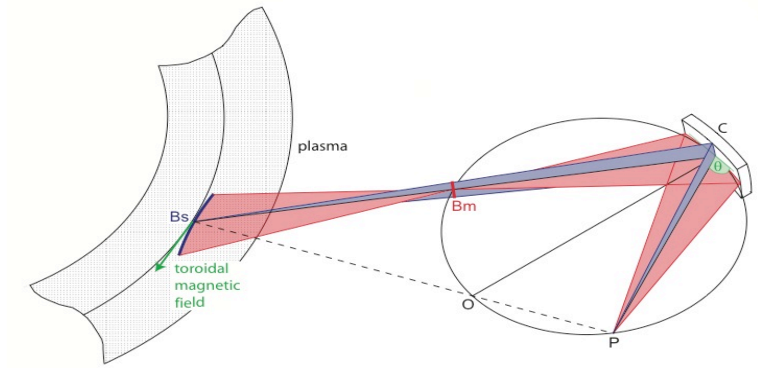
XGC Thermal-plasma simulation

- Gyrokinetic, full-f or delta-f PIC
- Can handle any field-line topology including open field-lines
  - Divertor and wall interactions
- Electromagnetic or electro-static turbulence
- Unstructured triangular mesh
  - fully parallel calculations
- Uses magnetic field distribution from separate MHD calculation. Tighter integration is proposed as part of Exascale initiative.



Imaging X-ray Spectroscopy

- Initially developed for magnetic fusion, deployed broadly
  - Profiles of T_i, T_e, rotation velocity
  - Time resolution like framing cameras

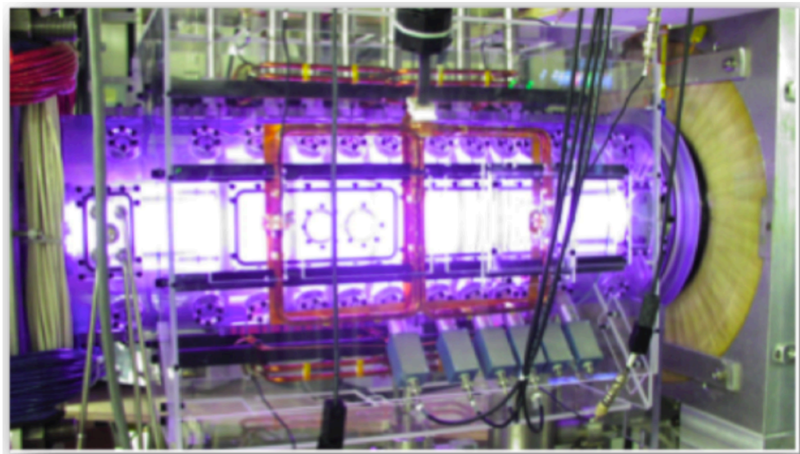


- Similar concepts developed for HEDP, lasers & pulsed power
  - OMEGA-EP, NIF
  - 1D profiles of Ti, Te, density
  - 2D imaging of compression

- Opportunities for MTF using forbidden EUV lines for measuring magnetic field
- Opportunities for medical imaging and EUV lithography

Collaborations with Private Companies (examples)

- Tri-Alpha Energy
  - 3D kinetic-MHD simulations (HYM) and neutral transport (DEGAS2)
  - Diagnostic systems and techniques
- Princeton Satellite Systems
  - FRC fusion-powered high-specific impulse rocket engine
  - Reduced neutron production in small fusion systems



PFRC-2 Experiment at PPPL

- Lockheed Martin
  - Hall effect thruster and spacecraft component plume interactions
- Corning, Inc.
  - Radiological analysis of glass

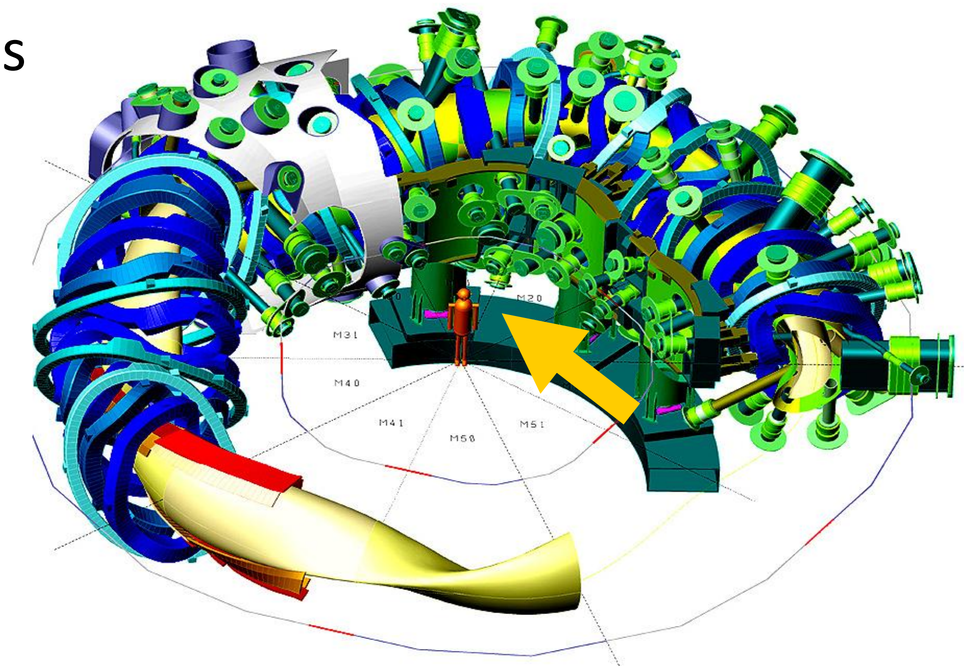
PPPL is actively interested in collaborating on fusion applications and approaches.

PPPL: Broad & Strong Collaborations

- Collaboration on PPPL activities

- Collaboration on world-wide experiment

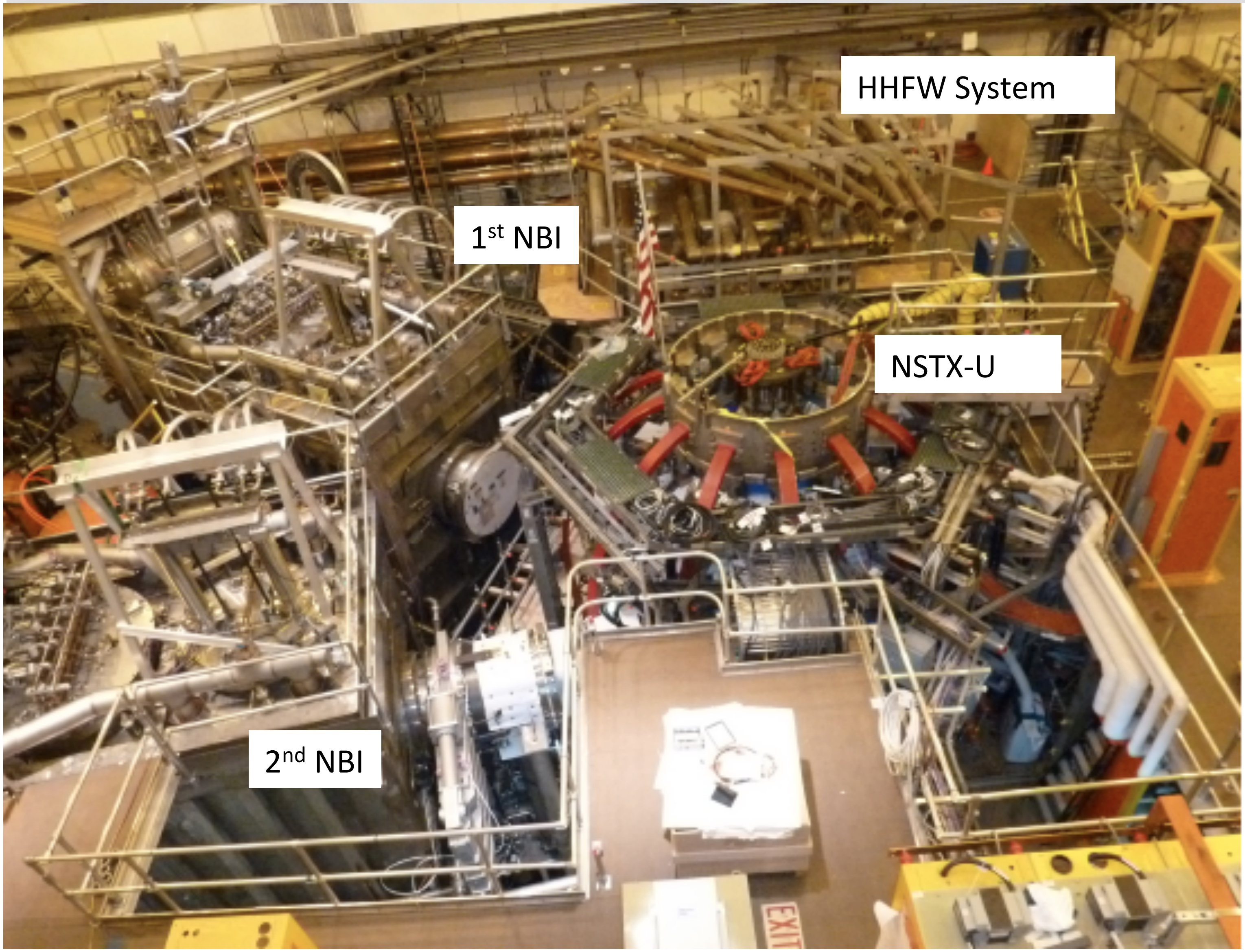
  DIII-D
  NIF, Omega
  Wendelstein 7-X (Germany)
  MAST (UK)
  KSTAR (S.Korea)
  EAST (China)
  ITER
  .
  .



W 7-X

- Experiment proposals
- Analysis and theory
- Diagnostics
- New facility components

NSTX Upgrade



Double B : 1 T

Double I_p : 2 MA

Double heating Power

5X in pulse length to 5 sec

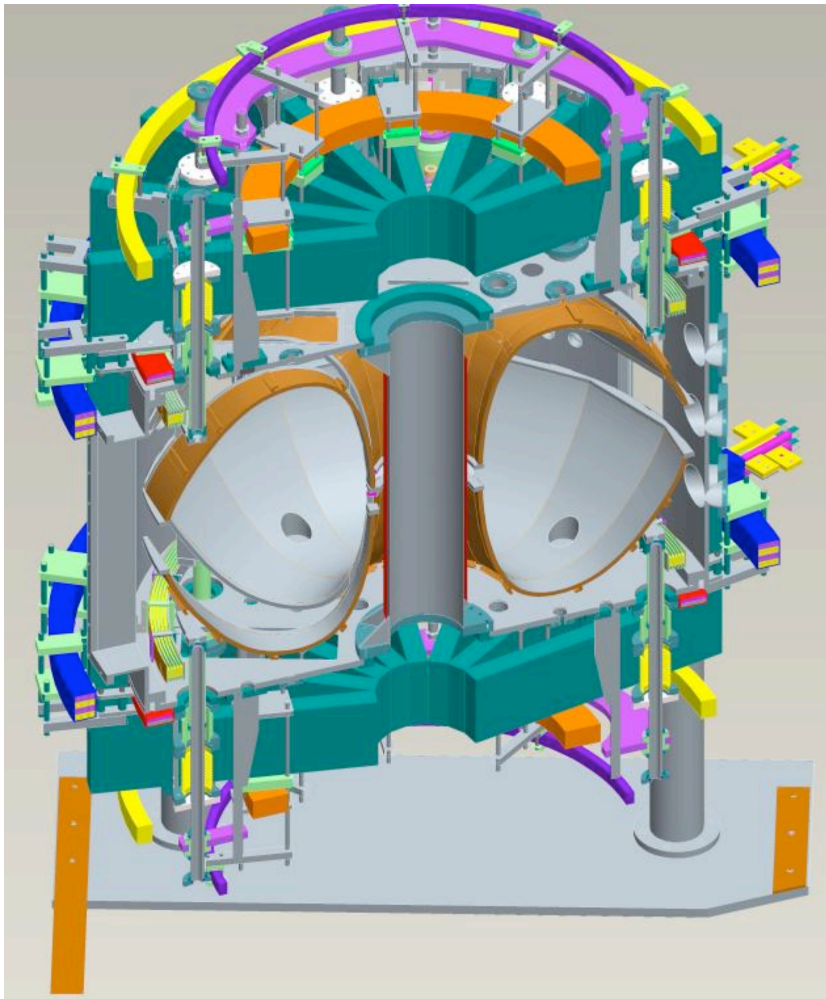
CD4 on schedule and budget.

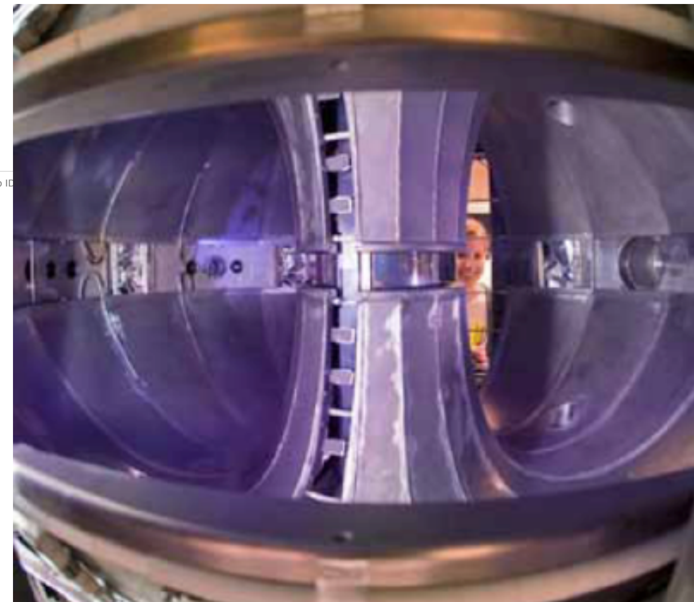
Research operation resumed: December 2015.

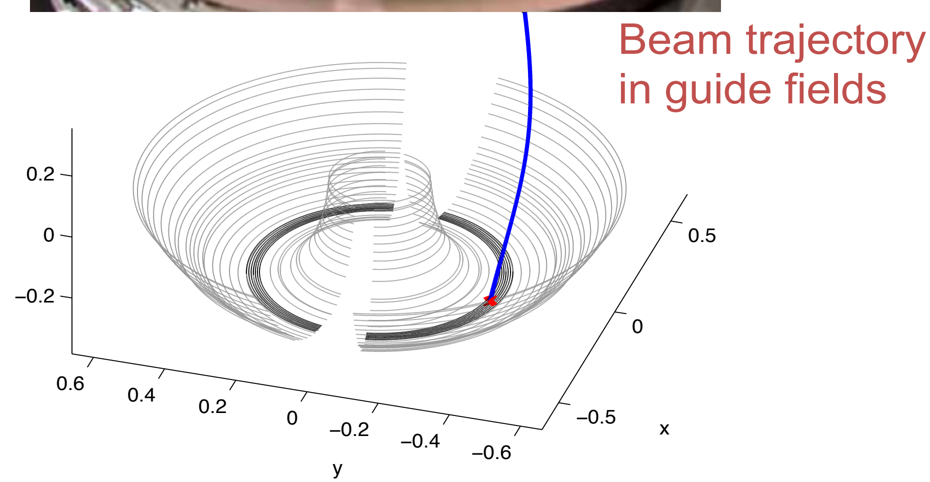
Lithium Tokamak Experiment (LTX)

an exploratory experiment

liquid Lithium wall (pool at bottom, coating by evaporation)



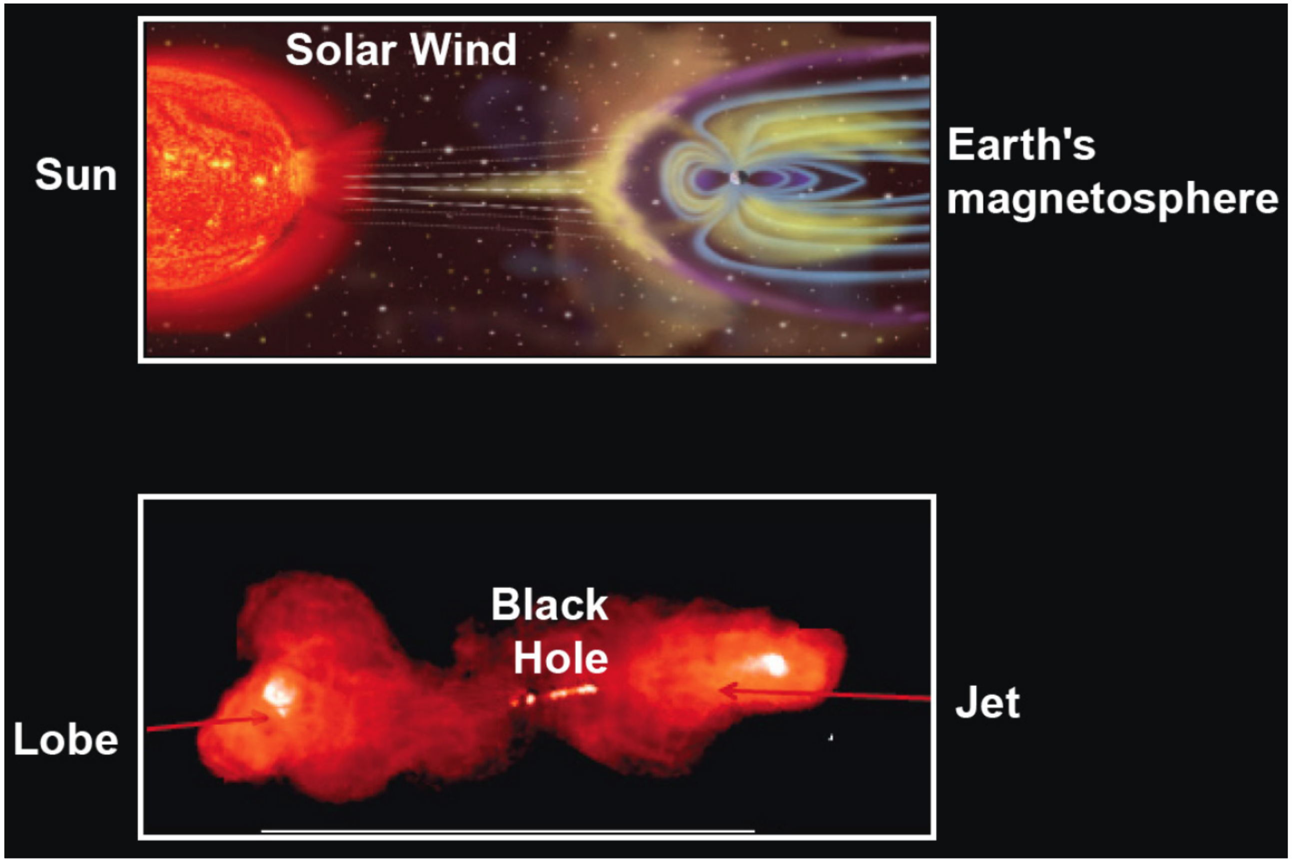




Plasma pervades the universe at all scales

Heliophysics
($<10^{-4}$ light year)

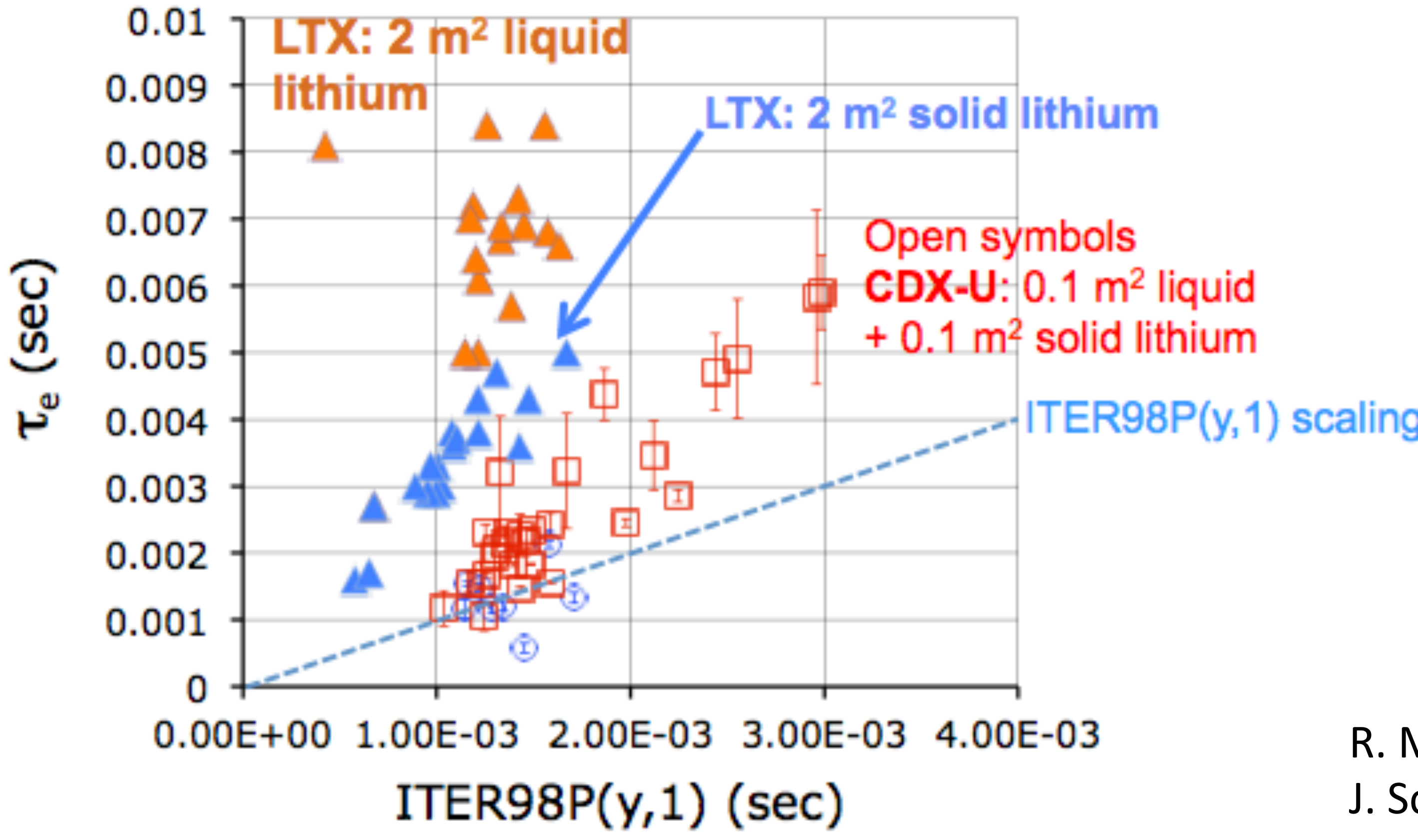
Astrophysics
($>10^{6}$ light year)



Major questions in astrophysics:

Dark energy drives expansion of the universe
Dark matter controls largest structures of the universe
Plasma processes are key in understanding much of the rest

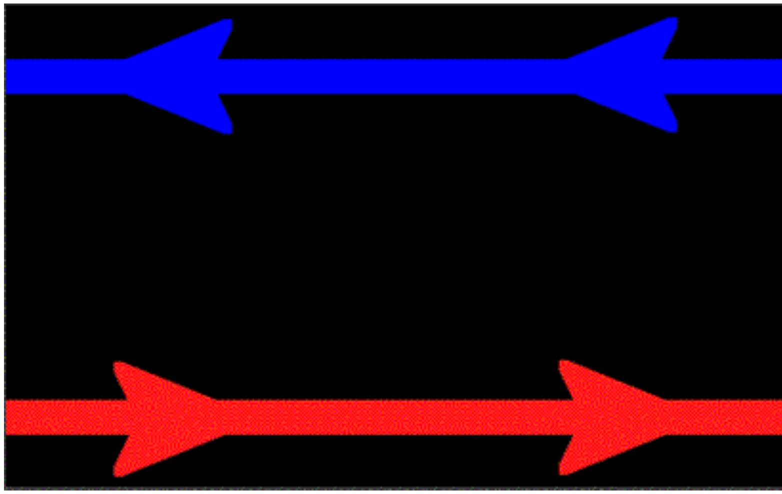
LTX -- Greatly Enhanced Confinement with Liquid Li Boundary

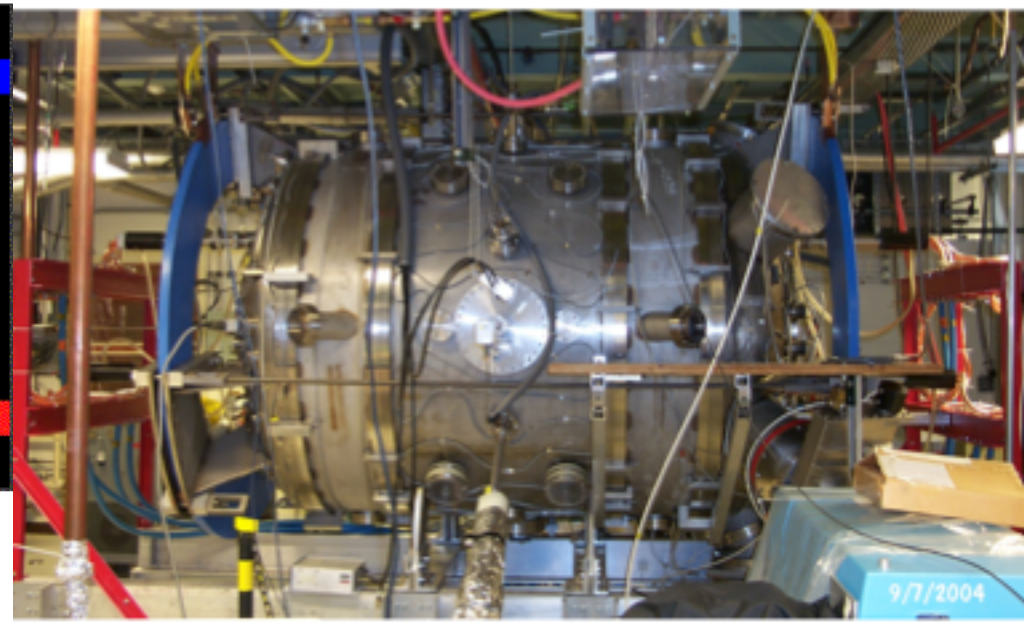


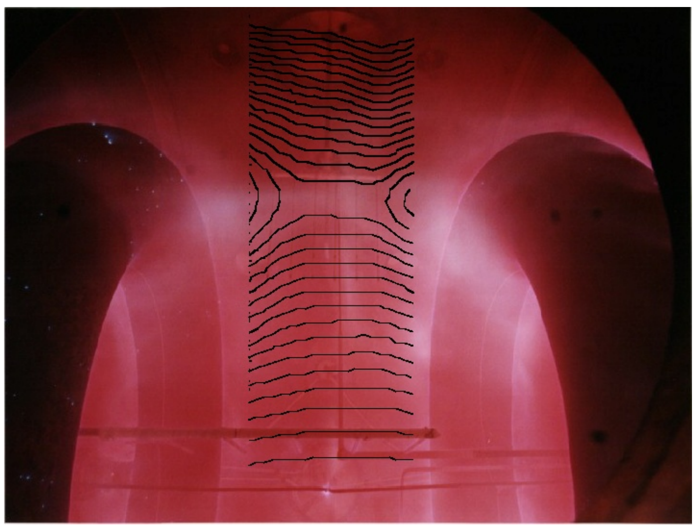
R. Majeski
J. Schmidt

- Confinement enhancements up to 10x standard scaling with liquid surface
- Will extend to 4 m^2 of liquid lithium surface
- Collaboration on EAST of flowing liquid lithium limiter

Magnetic Reconnection Experiment (MRX)







Reconnection affects stellar flares, magnetic storms, affects star formation, astrophysical jets, particle acceleration……….

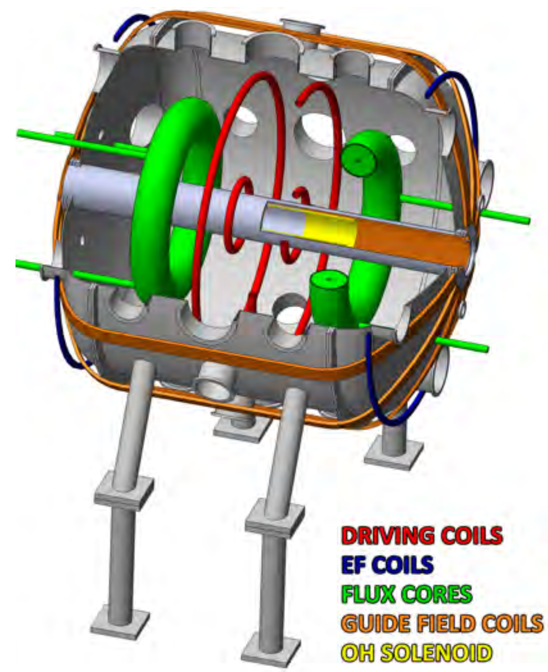
MRX has made pioneering contributions to magnetic reconnection,

New reconnection experiment under construction (FLARE)

- Reconnection in regimes more relevant to astrophysics
- Funded by NSF, through Princeton University
- ~ 40 committed "collaborative users" (experiment, theory, observation, space physics, astrophysics)
- Three year construction

  Cost ~ $4.3M,

  Including $1.2M University contribution



Plasma-based nanotechnology

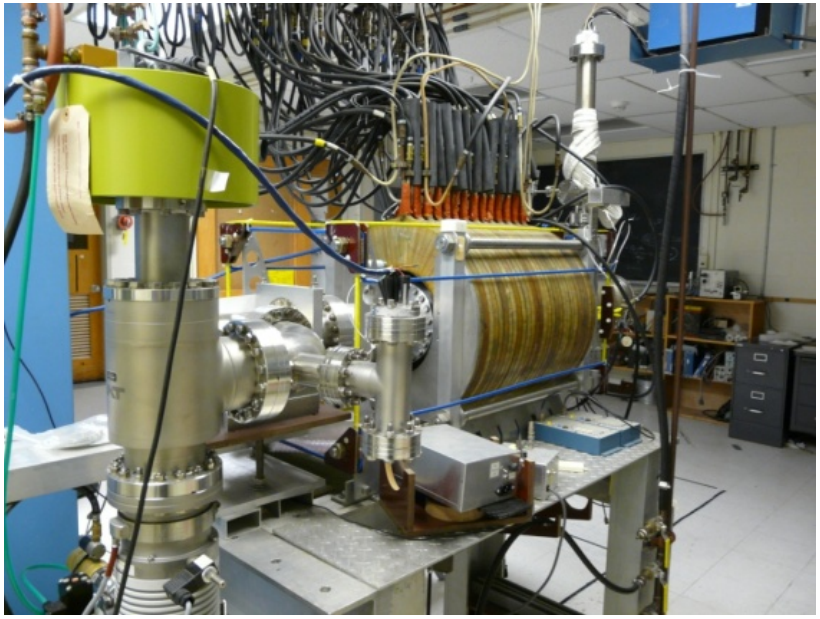
- New project funded by Basic Energy Sciences/DOE

  " Fundamental Studies of Synthesis of Nanomaterials: A joint challenge for plasma and materials sciences"

- Collaborators from

  George Washington University
  Case Western Reserve
  Princeton University

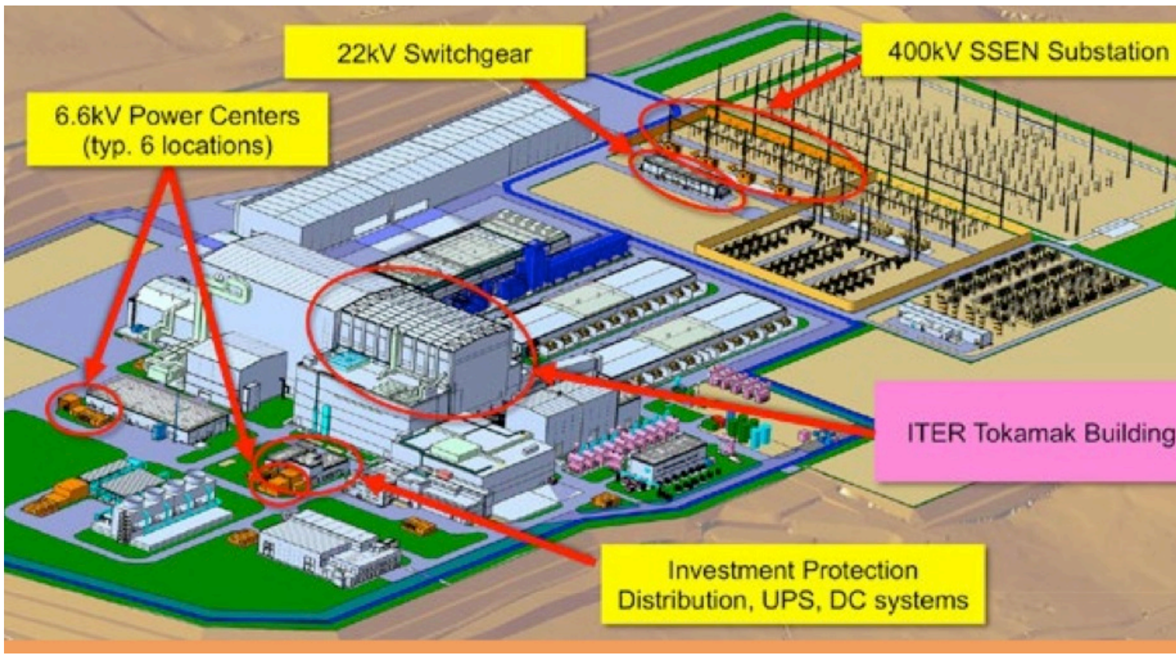
- Plasma nano lab setup using internal funds (LDRD)



- Plasmas offer possibility of high throughput, less fabrication cost, optimized material properties

- Challenge to understand plasma behavior, plasma-material interactions, and material properties

PPPL Collaborates Around the World
Design & Procurement of ITER steady state electric network

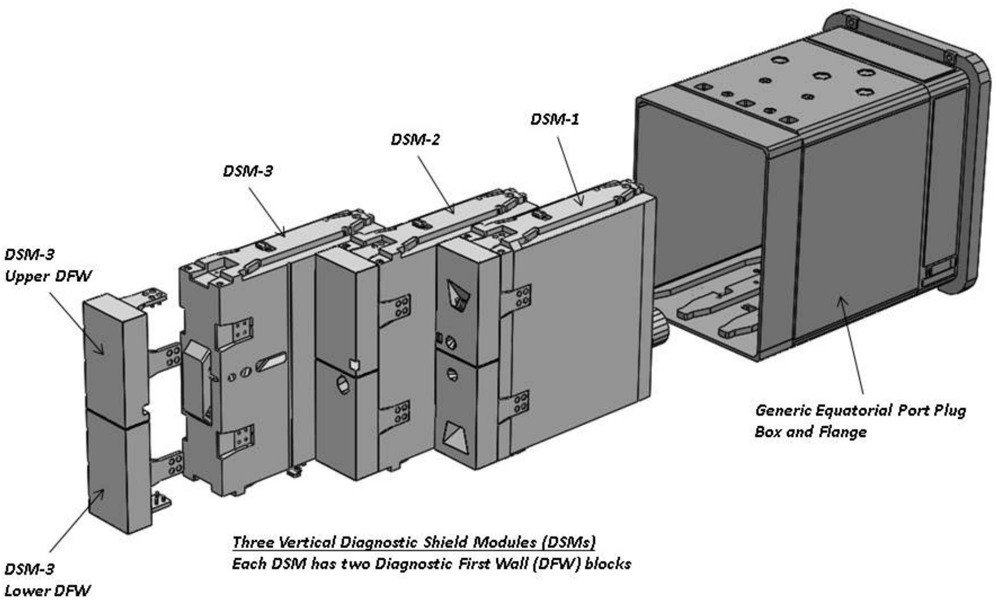


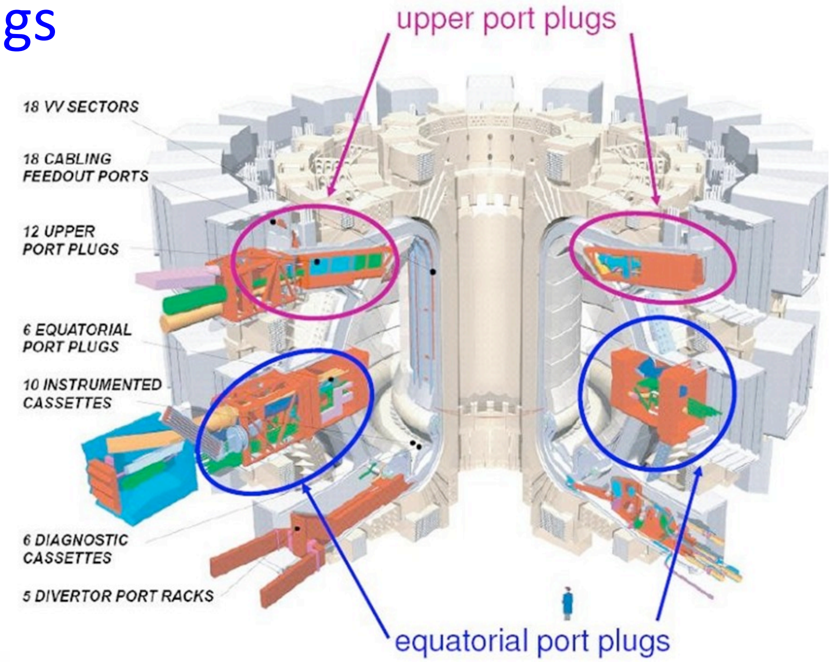
A success of technical and procurement challenges

PPPL Led Design of Some ITER Internal Systems

Using Integrated Design Capabilities

- System design for diagnostic port plugs





- Internal magnetic coils (in radiation field)